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FINAL REPORT; EARTH-MOON SIMULATOR

PART NUMBER 02080

JPL CONTRACT 950053

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August 1961

Prepared by

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Approved by

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FRONT/RV VIEW, NORTRONICS EARTH-MOON SIMULATOR  
SLIDES AND COMPARTMENTS OPEN  
(PHOTO 190752)

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## 1. INTRODUCTION

The purpose of this document is to report final information and tabular data concerning the Nortronics Earth-Moon Simulator. This simulator was manufactured under Nortronics Sales Order 02080; JPL Contract 950053.

Due to the relatively short period allowed for the simulator design, fabrication, test, delivery, and installation at JPL, certain design analyses initiated on the inception date of the contract have just been recently reduced into usable terms. Data which will further optimize and extend the effectiveness of the simulator is therefore herein included. Nortronics has taken the liberty to make definitive recommendations concerning this new data.



## 2. UNIQUE FEATURES OF THE NORTRONICS SIMULATOR COMPONENTS

### 2.1 Plexiglass

Black specular plexiglass outperforms the most efficient matte black as can be seen from the photograph of the baffles and parabolic mirror (see Figure 6.4). This photograph shows black anodized aluminum in contrast with the black specular surfaces. A comparison of the plexiglass surface to "coffin" paper is even more striking in contrast.

### 2.2 Power Supply

The power supply was custom designed and built specifically to meet the requirements of this lamp/simulator combination. It is the first transistorized current regulated, power supply (above 35 amps) ever designed or built with such regulation and stability.

### 2.3 Condensing-Lens System

The all-quartz mosaic, Kohler, system is the first of its kind having been custom designed and built by Nortronics to meet rigid homogeneity, high flux level, and large beam size requirements.

### 2.4 Parabolic Mirror

Design, size, and fabrication time have all contributed toward the parabolic mirror "challenge." Each one of these factors are discussed below.

2.4.1 Design - Nortronics chose the off-axis mirror design approach which is relatively unique in itself.

2.4.2 Size - The off-axis mirror is quite large. The 4-arc-second image quality which Nortronics has achieved with so large a mirror is unique.

2.4.3 Elapsed Time - Having been able to design, fabricate, deliver, and install the completely tested mirror within a 3-month period and the simulator within a 6-month period is also unique.



### 3. SPECTRAL DISTRIBUTION

In order to guarantee compliance with contractual commitments with regard to shipment of the simulator to JPL, Nortronics instigated a number of simultaneous engineering approaches to assure proper spectral distribution.

Under their respective headings, these engineering approaches and their relative merits are discussed. Data not available prior to shipment of the simulator is also included so that, based upon the analysis of this data by Nortronics, JPL may request further improvement of the spectral match to the sun (to whatever greater degree desired -- above and beyond the specifications provided to Nortronics). With this data JPL will be able to more fully test and analyze sensor characteristics.

#### 3.1 Xenon Lamp and Quartz Diffuser

As soon as an Osram xenon lamp and power supply were available, analysis was made of the lamp's relative spectral irradiance emitting through the quartz diffuser. The diffuser was reimaged into a Model 13 Perkin-Elmer through a spectrally flat 3-element (quartz, lithium-fluoride, quartz) lens. The curve shown in Figure 3.4, proved that a satisfactory spectral distribution was achievable through these two major components of the planned optical system.

#### 3.2 Analysis of Lamp and Optics

The xenon lamp, the mosaic, two uncoated aluminum mirrors, two diffusers, and the quartz field lens were reimaged into the Perkin-Elmer and analyzed. The data obtained (not herein reproduced) further assured Nortronics of satisfactory spectral distribution could be obtained.

#### 3.3 Keim Spectral Shifting Mirror

Nortronics attempted to compute a prescription to make a dichroic mirror which would meet the specified curve (resulting from the measurement of the simulators' spectral distribution as compared to the relative sun curve). It was determined that the small shift at the red end of the spectrum could not be accomplished without overcorrecting the response to the ultraviolet.

#### 3.4 Corning 4-70 Filter

An attempt was made by Nortronics to use a Corning 4-70 Filter to modify the simulator's distribution to more closely conform with that of the sun. Calculations indicated that this could be achieved by grinding and polishing the 4-70 Filter to .3mm (thickness). This required bonding the filter to a quartz base.



The filter was made except that it was polished out at .6mm. At this intermediate thickness, it shifted the spectrum too much at both extremes.

To approach the .3mm thickness probably would allow the filter to chip through and become wholly unusable. Later analysis of the completed simulator (without any further spectral shifting optics except those already in the optical system) proved that the JPL specifications were already met. However, improvement in spectral distribution may be achieved using the 4-70 (see Section 4).

### 3.5 Coating

Recoating of the two folding mirrors and the parabolic mirror to conserve more of the xenon lamp's energy in the ultraviolet would improve the system's similarity to the sun.

### 3.6 Relative Spectral Distribution

Figure 5.6 presents the Simulator "as delivered" spectral distribution compared to that of the sun. The Perkin-Elmer was used, after being accurately calibrated with the National Bureau of Standard lamp U-10, to analyze the simulator. The previously referred to 3-element lens was used to collimate the U-10 lamp output to the telescope on the Perkin-Elmer spectrophotometer. Since scatter is inherent in the blue and ultraviolet regions of the spectrophotometer, a 9863, and a W-39 + 9780 combination of filters had to be used to analyze the ultraviolet and blue to blue-green regions of the spectrum. This spectrum is so broad that a 1P28 and a 7102 photomultiplier had to be interchanged. Each photomultiplier was calibrated with its appropriate filter (as required). Since the response of the Perkin-Elmer optics, the photosensor, and the filters were common to both the simulator analysis and the NBS standard-lamp calibration, the resulting curve (recorded with the Perkin-Elmer) was divided by the calibration lamp in increments of 10 millimicrons across the spectrum to yield the simulator relative emittance data shown in Figure 5.6.

### 3.7 Absolute Irradiance

The absolute irradiance of the simulator was determined by the following method:

- 1) The luminosity was computed from irradiance indicated in column 5 of the JPL specifications. This was accomplished by:
  - a) multiplying the CIE visibility,  $V$ , constant, for each wavelength by the  $\text{watts/cm}^2$  for the same wavelength of the solar data (per the Geophysical Handbook),



- b) summing this over the visibility spectrum,
  - c) converting b) to luminosity by multiplying it by the luminous efficiency constant (680 lumens per watt), and
  - d) converting to  $\text{lm}/\text{ft}^2$  by multiplying by 929.
- 2) The ratio of the JPL-specified irradiance (for the  $5.411^\circ$  earth aperture), to the sun's irradiance (normal to the earth) was determined.
- 3) This ratio was multiplied by the luminosity received normal to the earth. The product yielded foot-candles being received from the earth.
- 4) With the calibrated photocell/filter package (having its response spectrally shifted to be equal to luminosity) the simulator output flux level was manually adjusted until it satisfied the calibrated level ( $14.7 \mu\text{A}$ ) demanded by the photocell. This is the operation that causes the simulator emittance to have the same integrated luminous energy that would be received 80,000 miles from earth (according to the JPL specification). The data appearing in Figure 5-6 indicates the efficiency with which the simulator simulates earth irradiance (over the spectrum from  $.35$  to  $.8 \mu$ ).

### 3.8 Equations for Irradiance & Illuminance from JPL "Earth"

The illumination received 80,000 miles in space from the JPL "earth" (with the photocell, filter, and meter calibrated to a  $6000^\circ\text{K}$  source in the Nortronics Standard Laboratory) is expressed as:

$$\int_{.38}^{.73} (\bar{y}) (H_0 \frac{\text{w}}{\text{m}^2}) \left( \frac{\text{m}^2}{1.10^4 \text{cm}^2} \right) (680 \frac{\text{lm}}{\text{w}}) \left( \frac{929 \frac{\text{cm}^2}{\text{ft}^2}}{\text{ft}^2} \right) = 12,843 \frac{\text{lm}}{\text{ft}^2} \text{ (which is foot-candles).}$$

Since

$$\int_0^\infty H_0 = 1396 \frac{\text{w}}{\text{m}^2} \text{ or } 0.1396 \frac{\text{w}}{\text{cm}^2} \text{ (e.g.: solar constant),}$$

and

JPL ( $5.4^\circ$  max.) specification is  $159.7 \times 10^{-6} \frac{\text{w}}{\text{cm}^2}$ ,

then

$$E_{5.4^\circ} = \left( \frac{159.7 \times 10^{-6} \frac{\text{w}}{\text{cm}^2}}{0.1396 \frac{\text{w}}{\text{cm}^2}} \right) 12,843 \frac{\text{lm}}{\text{ft}^2} = 14.69 \frac{\text{lm}}{\text{ft}^2}$$



where:  $\bar{y}$  = CIE visibility data

$H_s$  = irradiance of the sun

$E_{5.4}^{\prime \prime}$  = illumination from the JPL "earth" which subtends 5.4°.

Analysis of the spectral distribution was made operating the xenon lamp at 10 and 35 amperes. Within the repeatability of the Perkin-Elmer and the indeterminacy imposed by the use of different slit widths, no apparent spectrum shift occurred between .35 and .8 u. Another analysis was made using the 7 percent filter with the lamp operating at approximately 32 amperes. Within the same repeatability and indeterminacy discussed above, the only apparent spectrum shift was due to the slope of the filter as shown in Figure 5.11.

### 3.9 Change of Illumination as a Function of Displacement at Exit Port

In compliance with the JPL specification the 5-inch flux beam was analyzed by a photocell having a .4-inch diameter entrance pupil. Since the flux is limited to 5 inches, there will be an apparent falloff at the edges of the 5-inch port due to the vignetting of the .4-inch diameter pupil by the edge of the exit port. See Figure 5.13. To overcome this problem, Nortronics proposes a smaller photocell entrance pupil. A compound lead screw was used to control the Densicron probe. Two runs were made for each measurement plotted. It was not necessary to average the measurements because excellent stability and repeatability (within  $\pm 1/4$  percent) was achieved.

The four plots indicate satisfactorily the parameters in which all apertures operate.

### 3.10 Attenuating Filters

The attenuating filters were measured by Keim Precision Mirrors. The transmission values (from which the factors were determined) were measured in the simulator system using the illumination photocell and/or the El Dorado microphotometer. See Figure 5.11.

### 3.11 Optical Cement

At the plane of the first mosaic and the second 4-1/2-inch quartz refractor there is an FX 1057 cement bond. This cement has been measured for its ultraviolet transmission. See Figure 5.12.

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#### 4. RECOMMENDATIONS FOR FURTHER REFINEMENTS

As noted in Section 3.5, ultraviolet response would be improved by more optimum coating of the folding and parabolic mirrors. This application would also conserve xenon-lamp energy.

During the interim (since the simulator was shipped) Nortronics found that further improvement in spectral distribution would, in fact, result by using the Corning 4-70 filter previously discussed. By cutting the filter material into circular sections (.6 mm in thickness), and by judiciously placing these sections in the mosaic beam (one at a time), the response would be optimized, thus supplementing the improvement which could be achieved by overcoating the mirrors.

**N O R T R O N I C S**A DIVISION OF  
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<u>Shunt Selector Switch Position</u>	<u>Input Current (<math>\mu</math>A)</u>	<u>Meter Reads (<math>\mu</math>A)</u>	<u>Scale Ratios</u>
5	15.0	15.0	1/17.13
5	12.0	12.0	1/17.13
5	9.00	9.0	1/17.13
5	6.00	6.0	1/17.13
5	3.00	3.0	1/17.13
4	26.1	15.0	1/9.847
3	64.1	15.0	1/4.009
2	129.5	15.0	1/1.984
1	257.0	15.0	1.0

**Notes**

- 1) Photocell Selector Position: ILLUMINATION
- 2) Input current is from the meter-calibration power supply which has a current accuracy of  $\pm 0.05$  percent (or  $0.5 \mu$  Amperes).
- 3) For highest accuracy the meter face should be lightly tapped to allow the movement to overcome internal friction. This is especially required on the shunted ranges (Positions 1 through 4).
- 4) Terminal polarity: male = negative  
female = positive.
- 5) Calibration was performed in the Nortronics Cycle Laboratory on 20 July 1961.

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TABLE 5.2 PHOTOCELL RELATIVE SPECTRAL RESPONSE DATA (TYP)

$\lambda$	%	$\lambda$	%
.350	25	.525	90
.375	32	.550	96
.400	42	.575	99
.425	50	.600	92
.450	61	.625	67
.475	71	.650	34
.500	82	.675	15
		.700	10

Notes

Microns =  $\lambda$ , Relative Response = %

International Rectifier Corp. selenium photocell B30PL 3 x 3 inches with pigtails for feed through purposes (typical photocell from IRC curve)

TABLE 5.3 FILTER<sup>3)</sup> TRANSMISSION DATA (TYPICAL FILTER FROM EK FILTER HANDBOOK)

$\lambda$	t	$\lambda$	t	$\lambda$	t
.400	1.12	.520	51.3	.620	30.5
.420	.89	.540	64.2	.640	20.6
.440	1.23	.560	66.3	.660	15.2
.460	3.23	.580	58.0	.680	12.8
.480	14.0	.600	45.2	.700	12.0
.500	30.7				

Notes

Wavelength =  $\lambda$  (microns), % Transmittance = t

1) This filter is potted (with a gasket) to the photocell

2) National Bureau of Standards luminous standard #4262, used for reference lamp calibration

3) EK-W-102 filter

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### 5.1 Photocell/Filter Calibration Notes

In collecting the following data, a Chance Bros. OB-8 color shifting filter (with 14.4 percent transmission to a 2870°K source) was used. This filter shifted the color temperature to represent 6000°K.

The photocell was calibrated in the Nortronics Photometric Standards Laboratory.

Calibration values:

6000°K Source			2870°K Source		
Photocell ( $\mu$ A)	Illumination (Ft candles)	Position #	Photocell ( $\mu$ A)	Illumination (Ft candles)	Position #
15	15.1	1	15	16.75	1

A constant has to be used (for this particular photocell and filter), relating the "red" to "blue" calibrations, due to the fact that this combination does not perfectly match the CIE  $\bar{y}$  tristimulus value. However, this constant (15.1/16.75) enables calibrations to be made with only the "red" standard. If a change of the photocell/filter sensitivity is indicated, a new calibration value must be used (presently  $c = 14.6\mu$  Amperes).

### 5.2 Linearity of El Dorado Microphotometer

The El Dorado microphotometer was used to establish a relationship of the angular field of view of the earth to the illumination received at the exit port for each aperture. With the smallest apertures a spectrally flat 3-element (quartz, lithium-fluoride, quartz) lens was used to focus the apertures onto the photocell (S-4 used with opal glass). For further linearity details refer to the JPL Earth-Moon Simulator Progress Report #6 for the week ending May 23, 1961.

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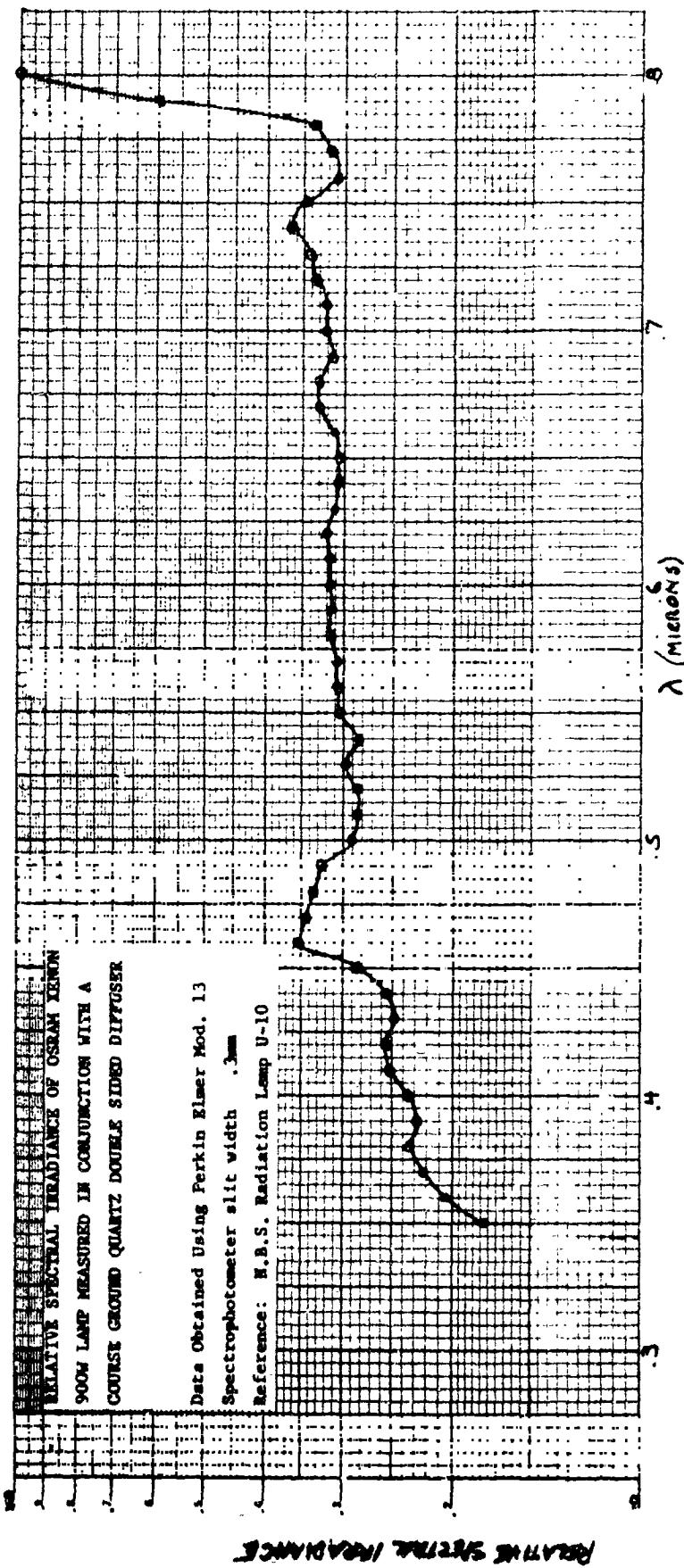


TABLE 5.4

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TABLE 5.5 REALTIVE SPECTRAL IRRADIANCE VS. WAVELENGTH

<u>R.S.I.</u>	$\lambda$	<u>R.S.I.</u>	$\lambda$
.164	.330	.309	.570
.173	.340	.316	.580
.178	.350	.314	.590
.205	.360	.315	.600
.223	.370	.318	.610
.235	.380	.320	.620
.228	.390	.312	.630
.236	.400	.305	.640
.251	.410	.305	.650
.255	.420	.312	.660
.248	.430	.329	.670
.257	.440	.330	.680
.282	.450	.313	.690
.353	.460	.320	.700
.347	.470	.320	.710
.336	.480	.332	.720
.325	.490	.340	.730
.290	.500	.366	.740
.285	.510	.347	.750
.298	.520	.310	.760
.283	.530	.315	.770
.304	.540	.336	.780
.305	.550	.602	.790
.305	.560	1.000	.800

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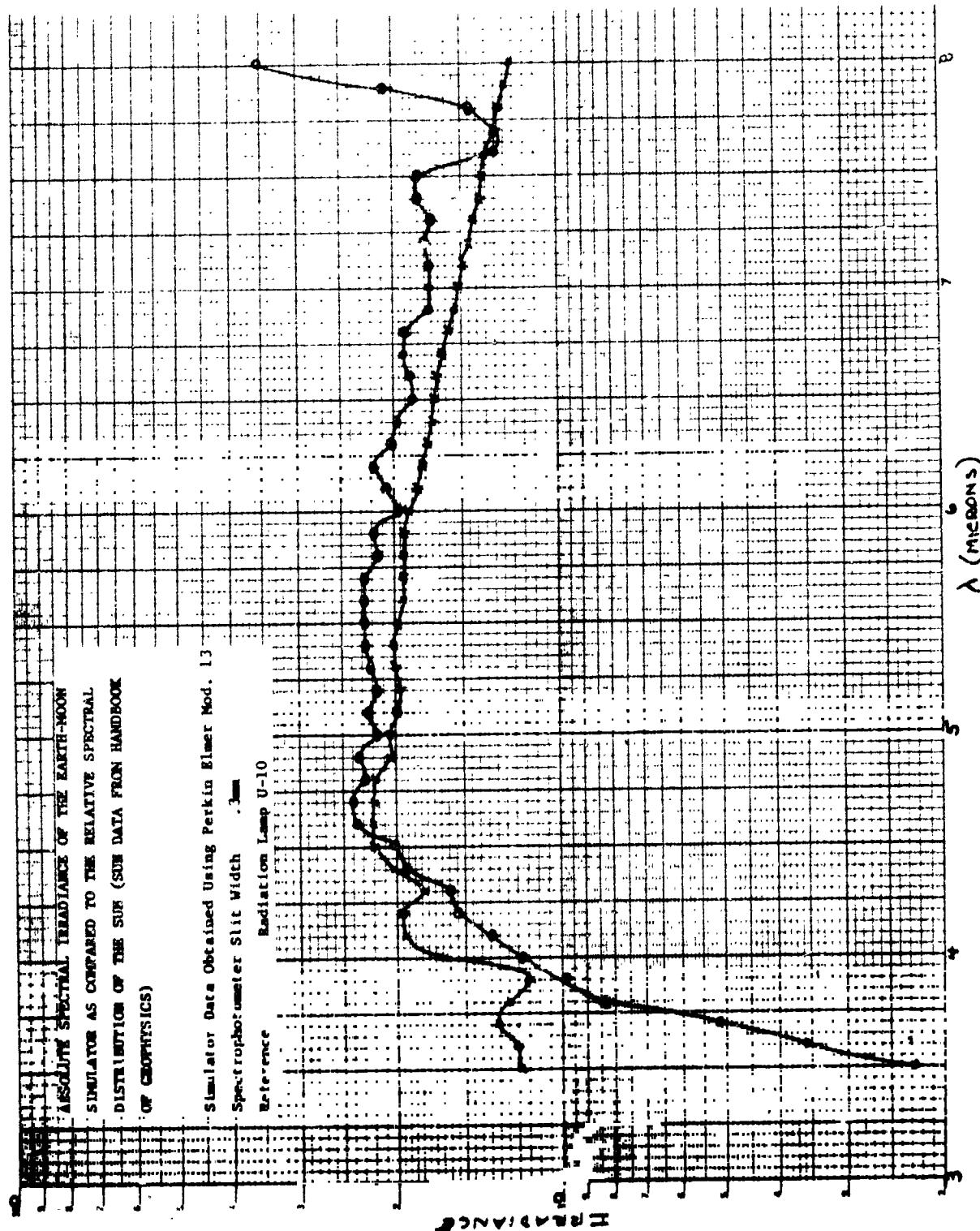


TABLE 5.6

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TABLE 5.7 IRRADIANCE VS. WAVELENGTH

<u>Watts/cm<sup>2</sup></u>	<u>λ</u>	<u>Watts/cm<sup>2</sup></u>	<u>λ</u>
$2.28 \cdot 10^{-7}$	.350	$2.13 \cdot 10^{-6}$	.580
$3.59 \cdot 10^{-7}$	.360	$2.19 \cdot 10^{-6}$	.590
$5.17 \cdot 10^{-7}$	.370	$1.96 \cdot 10^{-6}$	.600
$8.34 \cdot 10^{-7}$	.380	$2.08 \cdot 10^{-6}$	.610
$9.88 \cdot 10^{-7}$	.390	$2.18 \cdot 10^{-6}$	.620
$1.18 \cdot 10^{-6}$	.400	$2.01 \cdot 10^{-6}$	.630
$1.34 \cdot 10^{-6}$	.410	$1.96 \cdot 10^{-6}$	.640
$1.55 \cdot 10^{-6}$	.420	$1.84 \cdot 10^{-6}$	.650
$1.59 \cdot 10^{-6}$	.430	$1.86 \cdot 10^{-6}$	.660
$1.90 \cdot 10^{-6}$	.440	$1.92 \cdot 10^{-6}$	.670
$2.01 \cdot 10^{-6}$	.450	$1.91 \cdot 10^{-6}$	.680
$2.36 \cdot 10^{-6}$	.460	$1.73 \cdot 10^{-6}$	.690
$2.39 \cdot 10^{-6}$	.470	$1.72 \cdot 10^{-6}$	.700
$2.28 \cdot 10^{-6}$	.480	$1.71 \cdot 10^{-6}$	.710
$2.32 \cdot 10^{-6}$	.490	$1.74 \cdot 10^{-6}$	.720
$2.14 \cdot 10^{-6}$	.500	$1.68 \cdot 10^{-6}$	.730
$2.23 \cdot 10^{-6}$	.510	$1.79 \cdot 10^{-6}$	.740
$2.16 \cdot 10^{-6}$	.520	$1.79 \cdot 10^{-6}$	.750
$2.20 \cdot 10^{-6}$	.530	$1.30 \cdot 10^{-6}$	.760
$2.25 \cdot 10^{-6}$	.540	$1.29 \cdot 10^{-6}$	.770
$2.26 \cdot 10^{-6}$	.550	$1.44 \cdot 10^{-6}$	.780
$2.27 \cdot 10^{-6}$	.560	$2.08 \cdot 10^{-6}$	.790
$2.27 \cdot 10^{-6}$	.570	$3.51 \cdot 10^{-6}$	.800

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EARTH MOON SIMULATOR'S CHANGE OF IRRADIANCE AS A FUNCTION OF HORIZONTAL AND VERTICAL DISPLACEMENT ACROSS THE EMITTING BEAM

Data: Welch Densicron

Probe Aperture: .5 Inches

Earth Angle: 5.4 Degrees

Separation Probe to Exit Port: 18 Inches

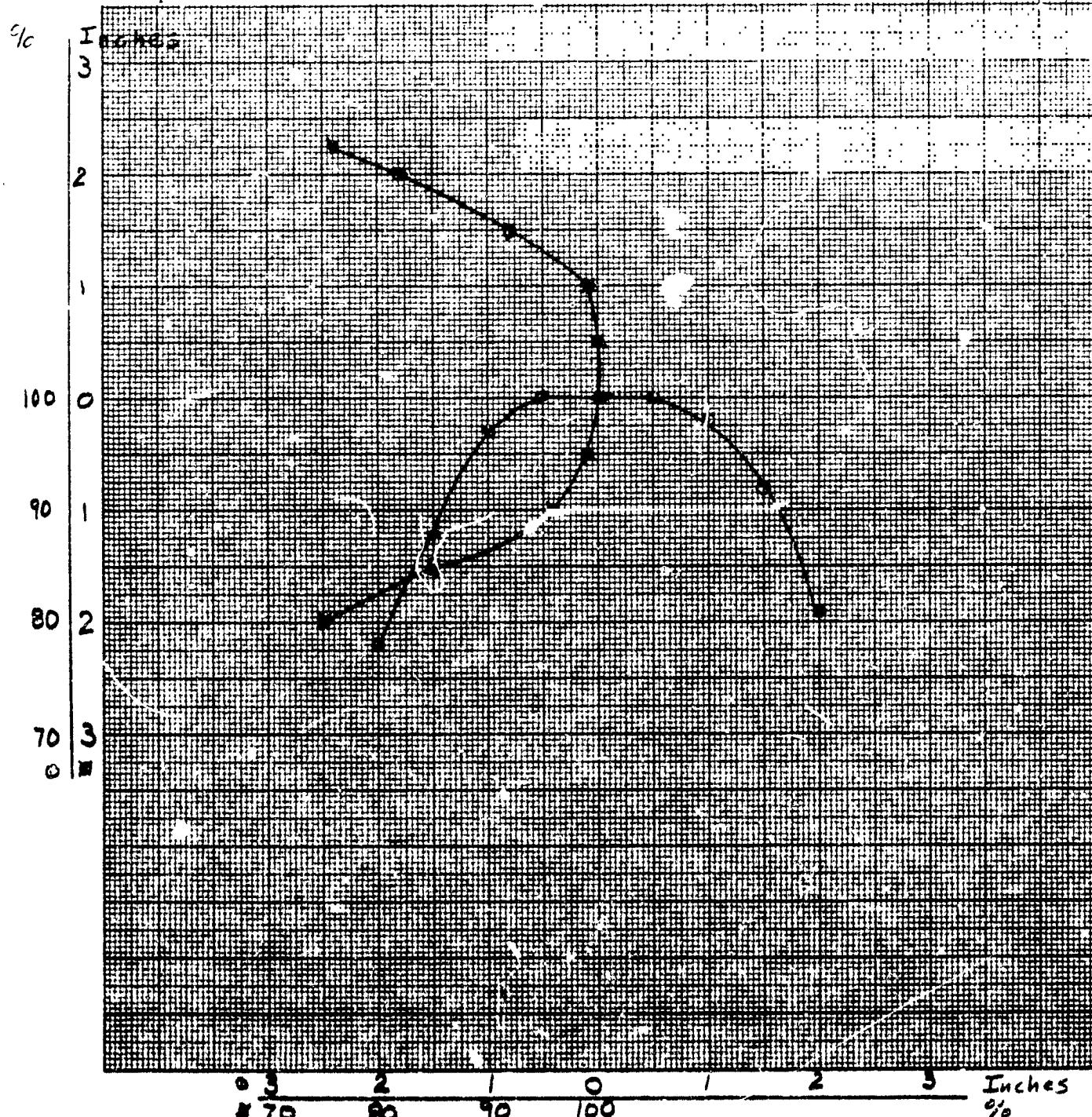


TABLE 5.8

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EARTH MOON SIMULATOR'S CHANGE OF IRRADIANCE AS A FUNCTION OF VERTICAL DISPLACEMENT ACROSS THE EMITTING BEAM

Data: Welch Densicron

Probe Aperture: .5 Inches

Earth Angle: 2.9 Degrees

Separation Probe to Exit Port: 7 Inches

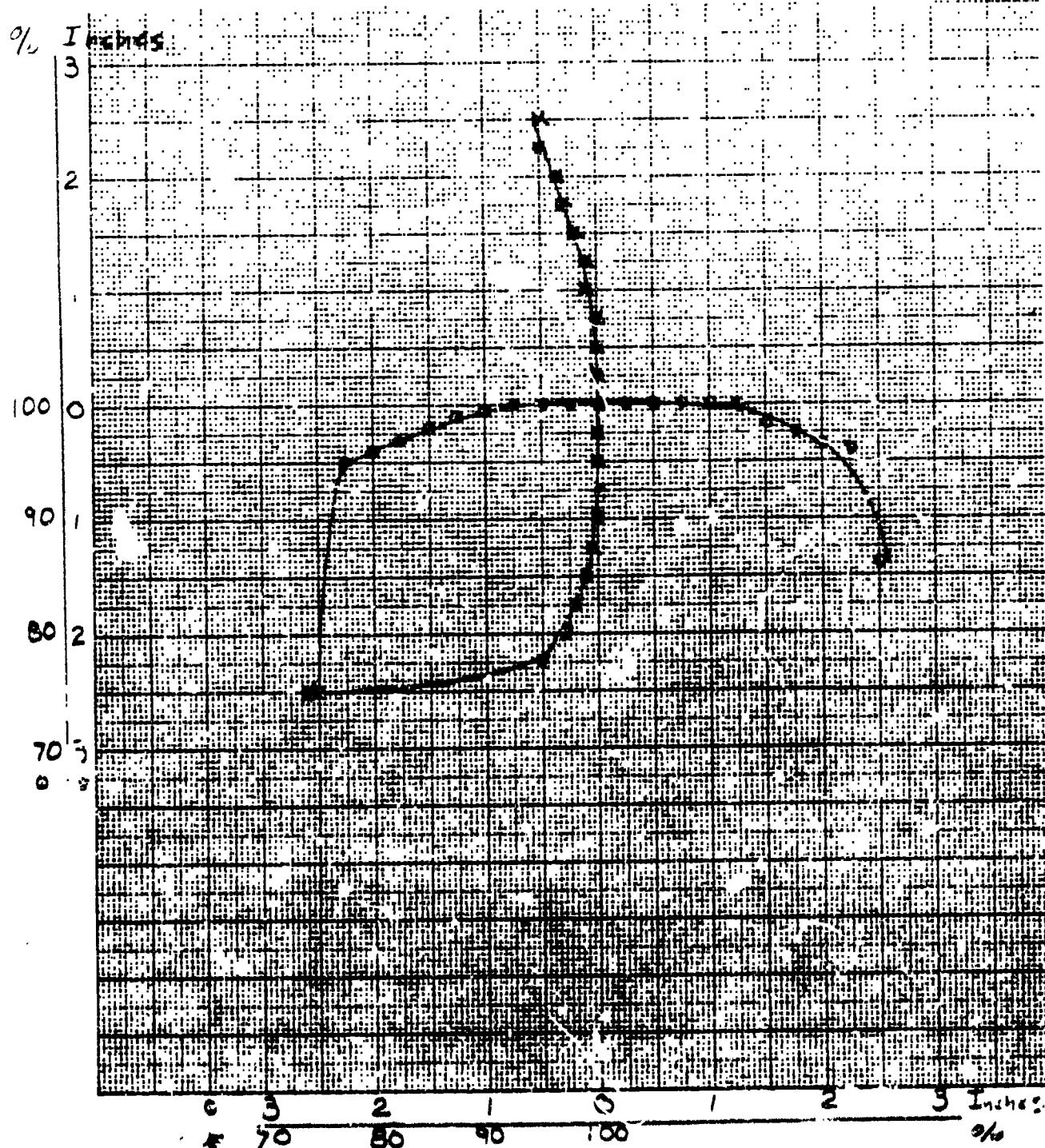


TABLE 5.9

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INSERTION OF BAFFLES, NORTRONICS EARTH-MOON SIMULATOR  
(PHOTO 190833)

FIGURE 6.3

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FIGURE 6.4

INTERIOR VIEW SHOWING PARABOLIC MIRROR, SPACERS, AND BAFFLES.  
NORTRONICS EARTH-MOON SIMULATOR (PHOTO 19083)

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RIGHT SIDE VIEW, NORTRONICS EARTH-MOON  
SIMULATOR (PHOTO 190747)

FIGURE 6.5

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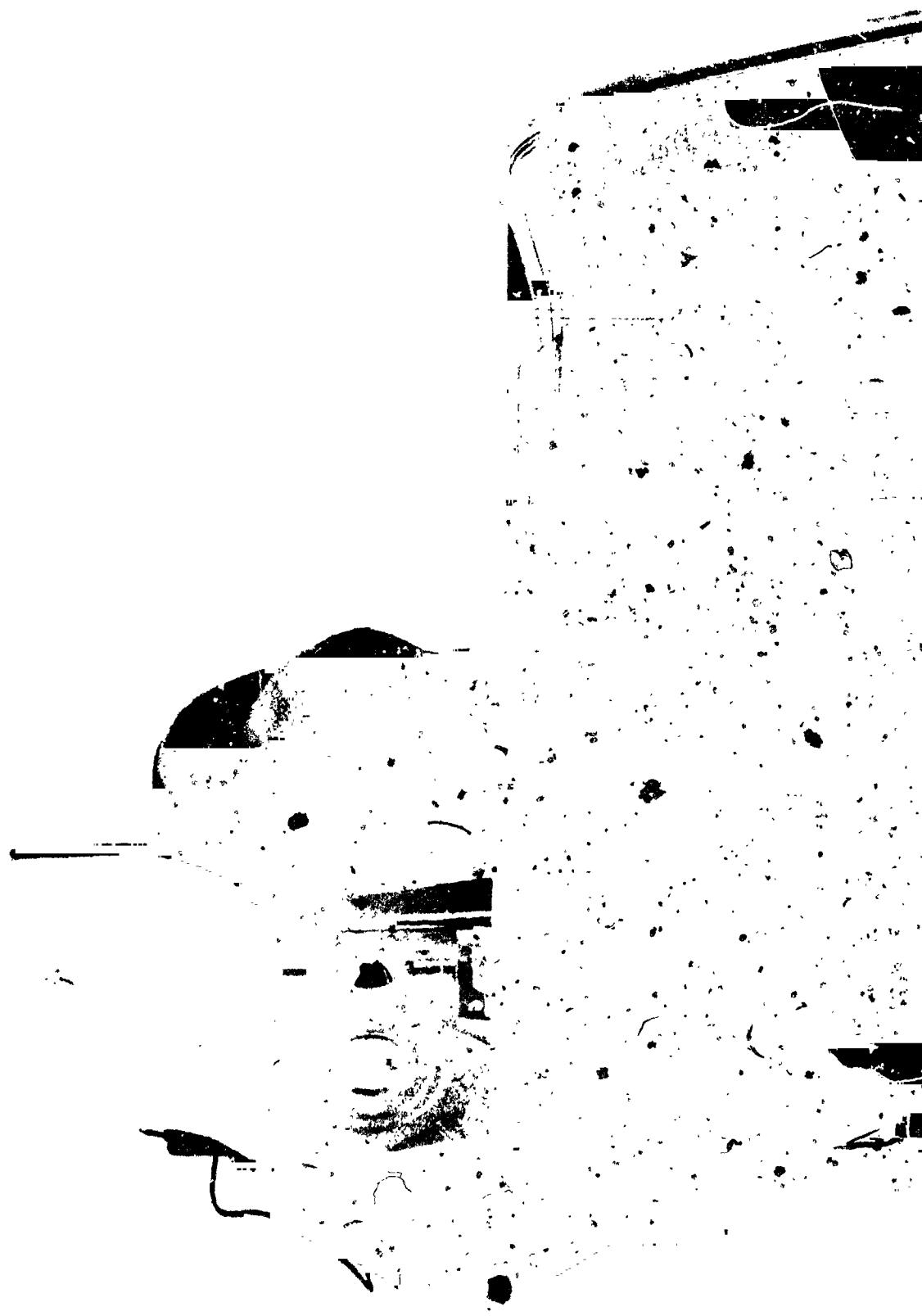
RS/BACK VIEW, NORTRONICS EARTH-MOON SIMULATOR  
(PHOTO 190753)

FIGURE 6.6

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RS/BACK VIEW, NC.TRONICS EARTH-MOON SIMULATOR,  
XENOSOL LAMPHOUSE OPENED  
(PHOTO 190748)

FIGURE 6.7

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EARTH MOON SIMULATOR'S CHANGE OF IRRADIANCE AS A FUNCTION OF HORIZONTAL AND VERTICAL DISPLACEMENT ACROSS THE EMITTING BEAM

Data: Welch Densicron

Probe Aperture: .5 Inches

Earth Angle: 2.9 Degrees

Separation Probe to Exit Port: 18 Inches

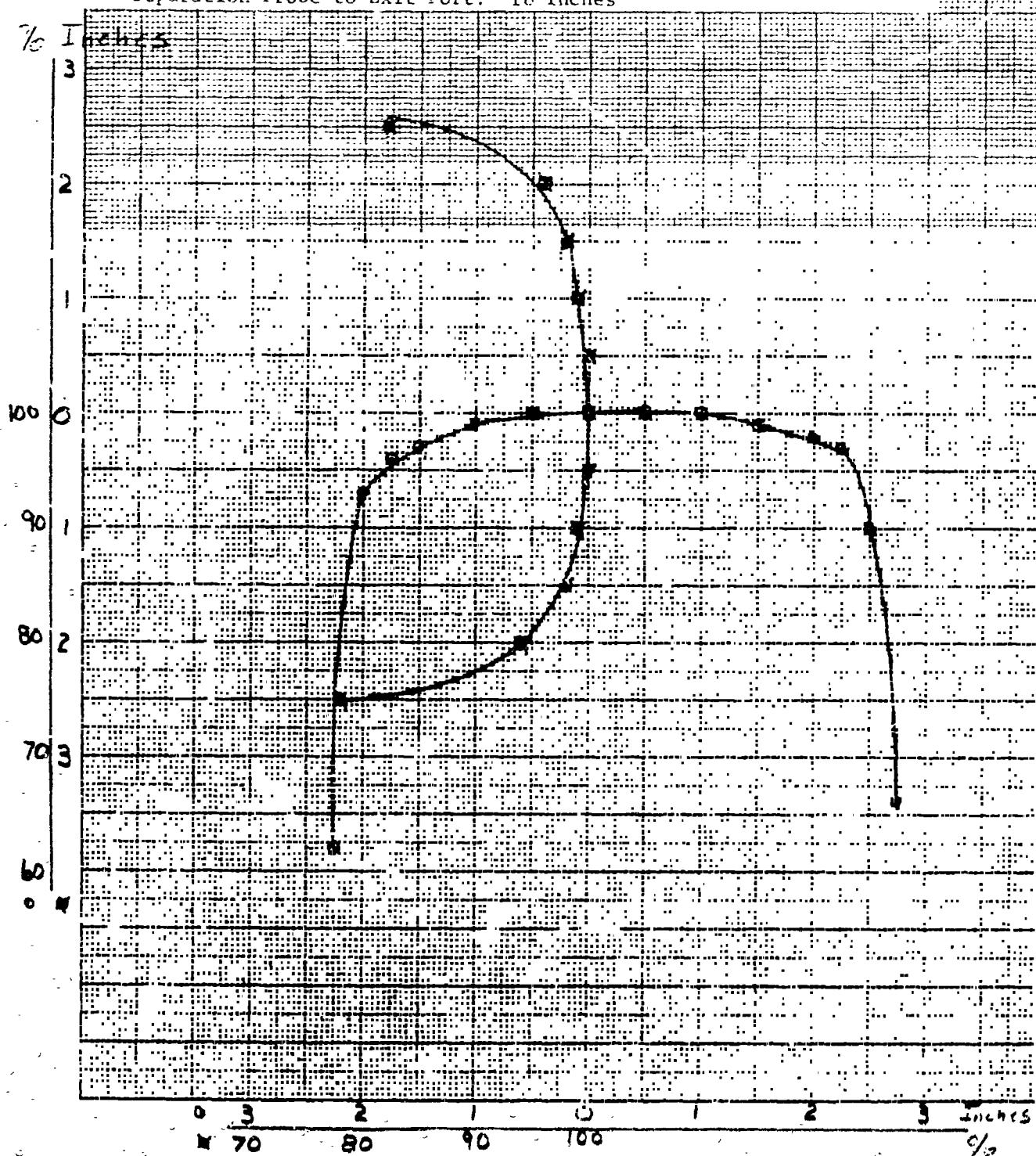


TABLE 5.10

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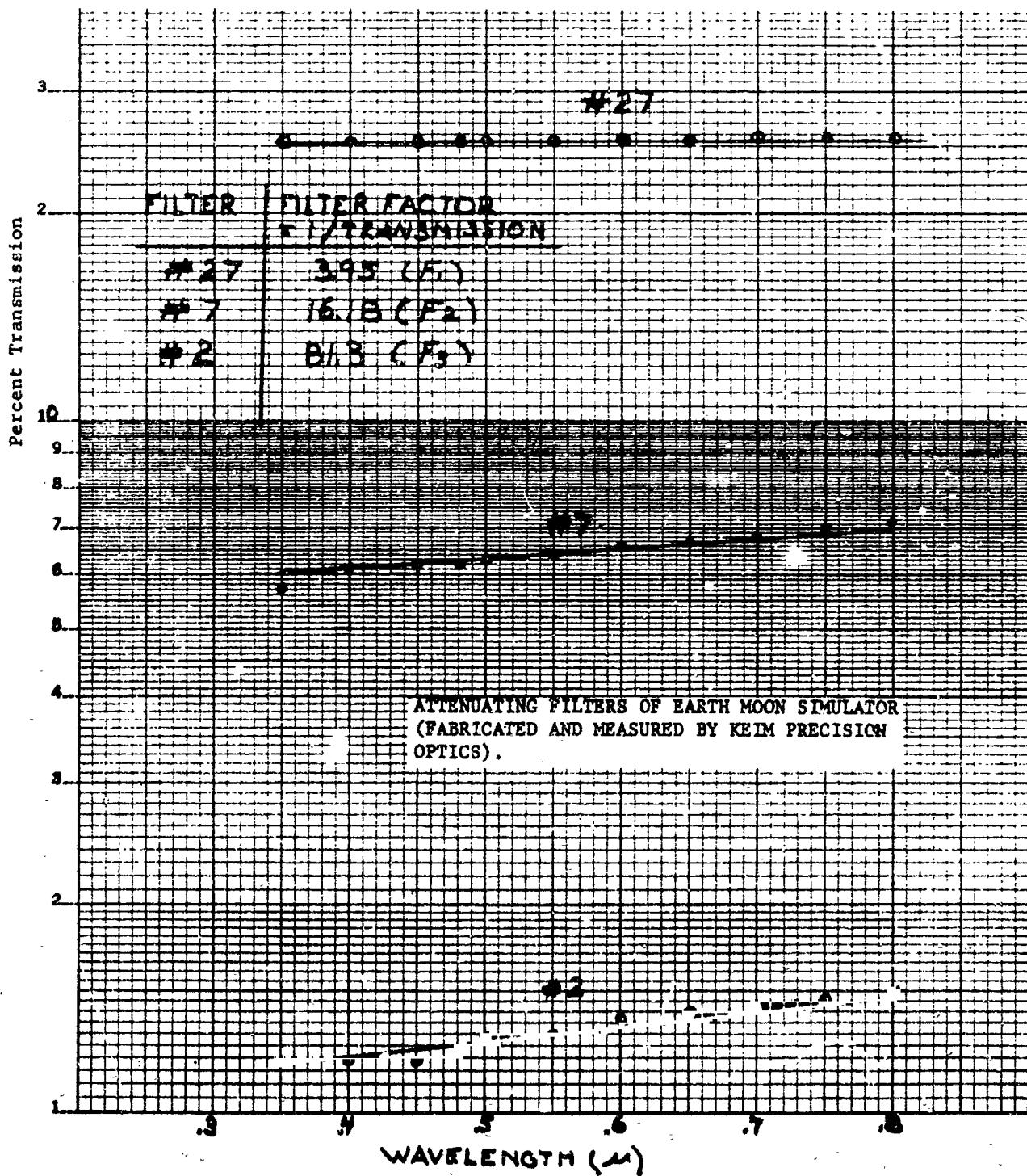


TABLE 5.11

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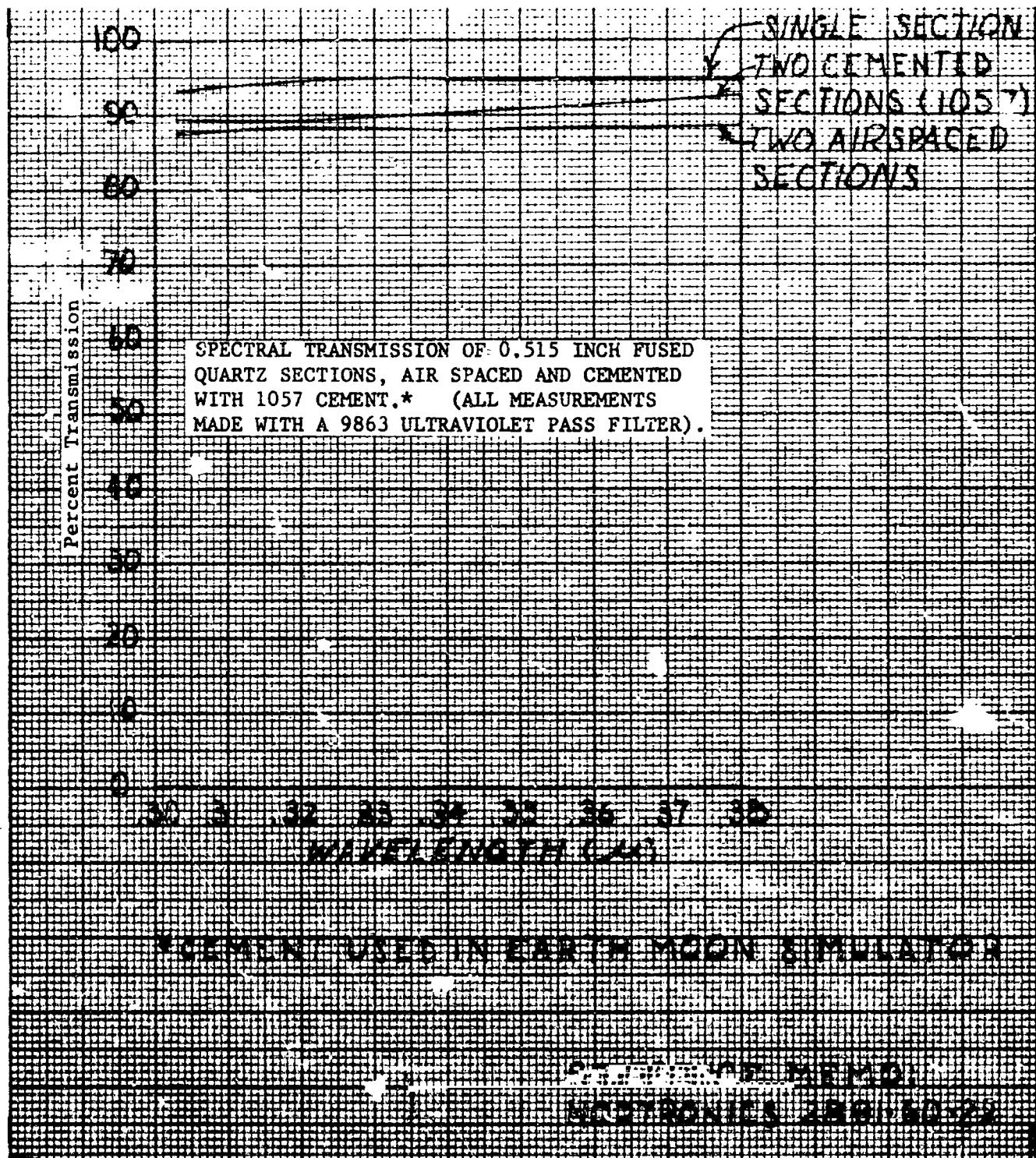


TABLE 5.12

N O R T R O N I C S



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EARTH MOON SIMULATOR CHANNEL OF IRRADIANCE IS A FUNCTION OF HORIZONTAL AND VERTICAL DISPLACEMENT ACROSS THE EMITTING BEAM

Data: Welch Densicron

Probe Aperture: .3 Inch Diameter Semidiffused

Earth Angle: 5.4 Degrees

Separation Probe to Exit Port: 7 Inches

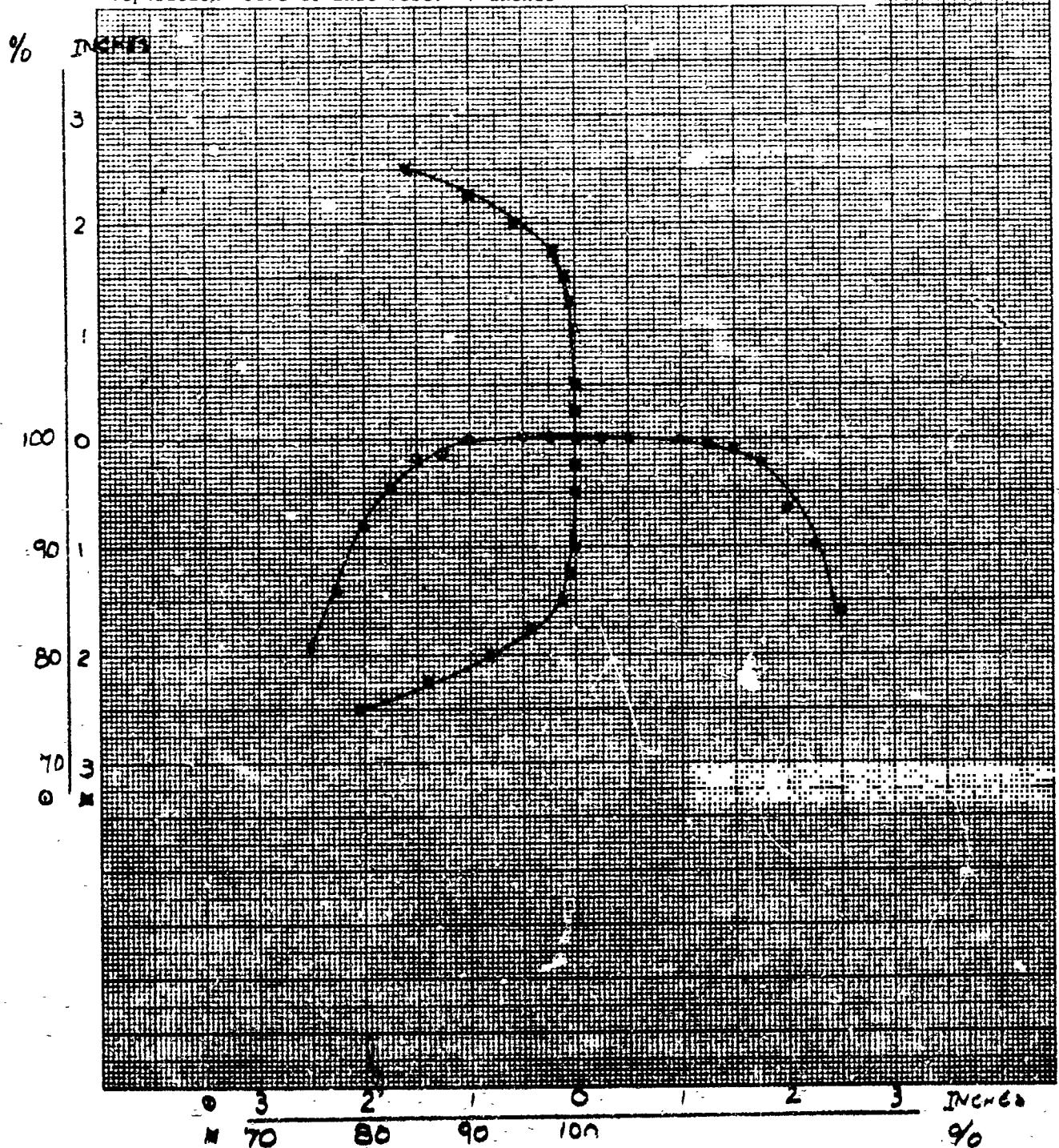


TABLE 5.13

N O R T R O N I C S



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6. PHOTOGRAPHS

Photographs of the Nortronics Earth-Moon Simulator and its support equipment have been reproduced on the following pages.

N O R T R O N I C S



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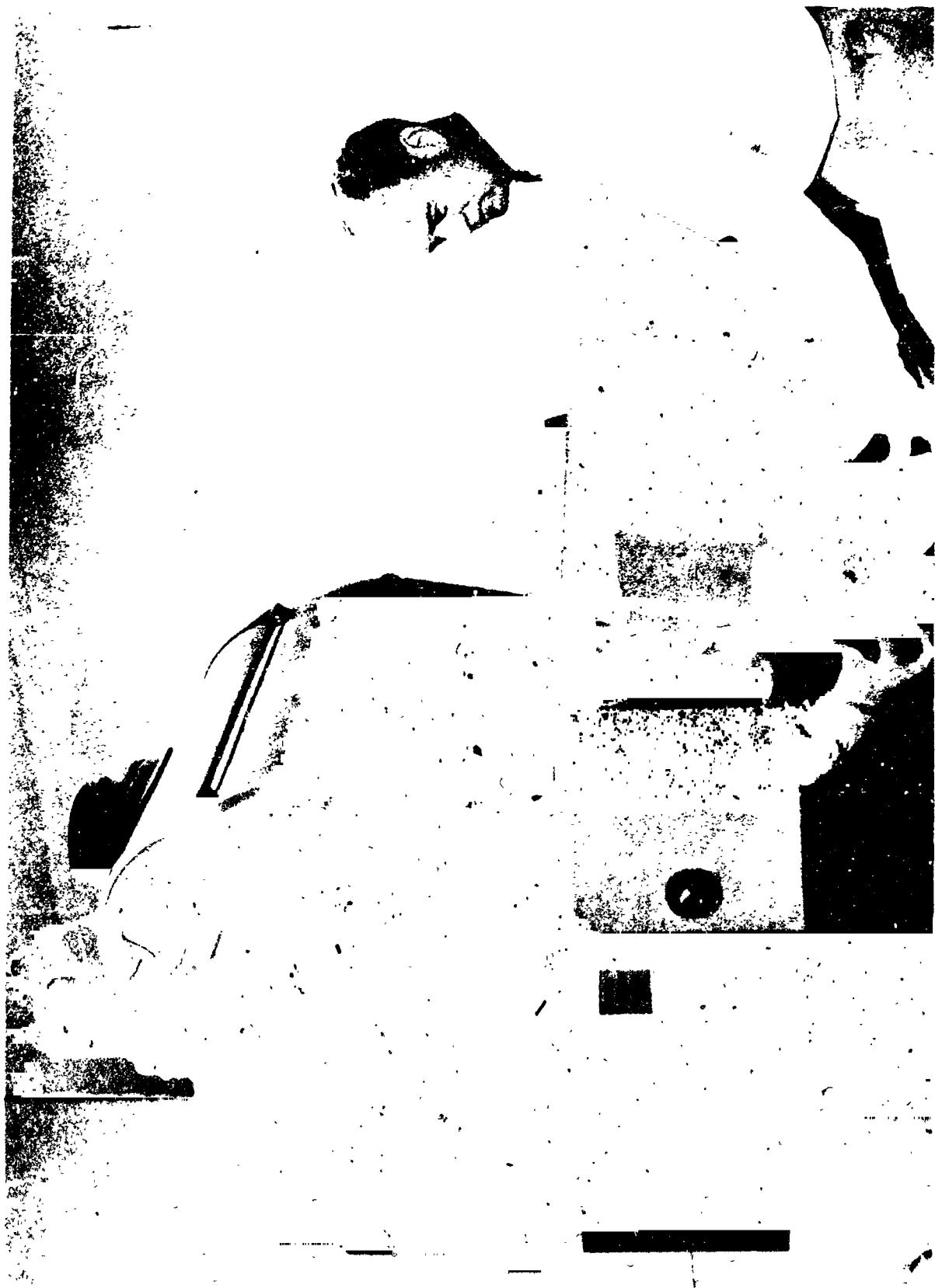
FRONT VIEW, NORTRONICS EARTH-MOON SIMULATOR  
(PHOTO 190746)

FIGURE 6.1

N O R T R O N I C S



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METAL SIDE PANEL REMOVED TO SHOW BLACK PLEXIGLASS SIDE PANEL OF  
NOKTRONICS EARTH-MOON SIMULATOR (PHOTO 190832)

FIGURE 6.2

N O R T R O N I C S



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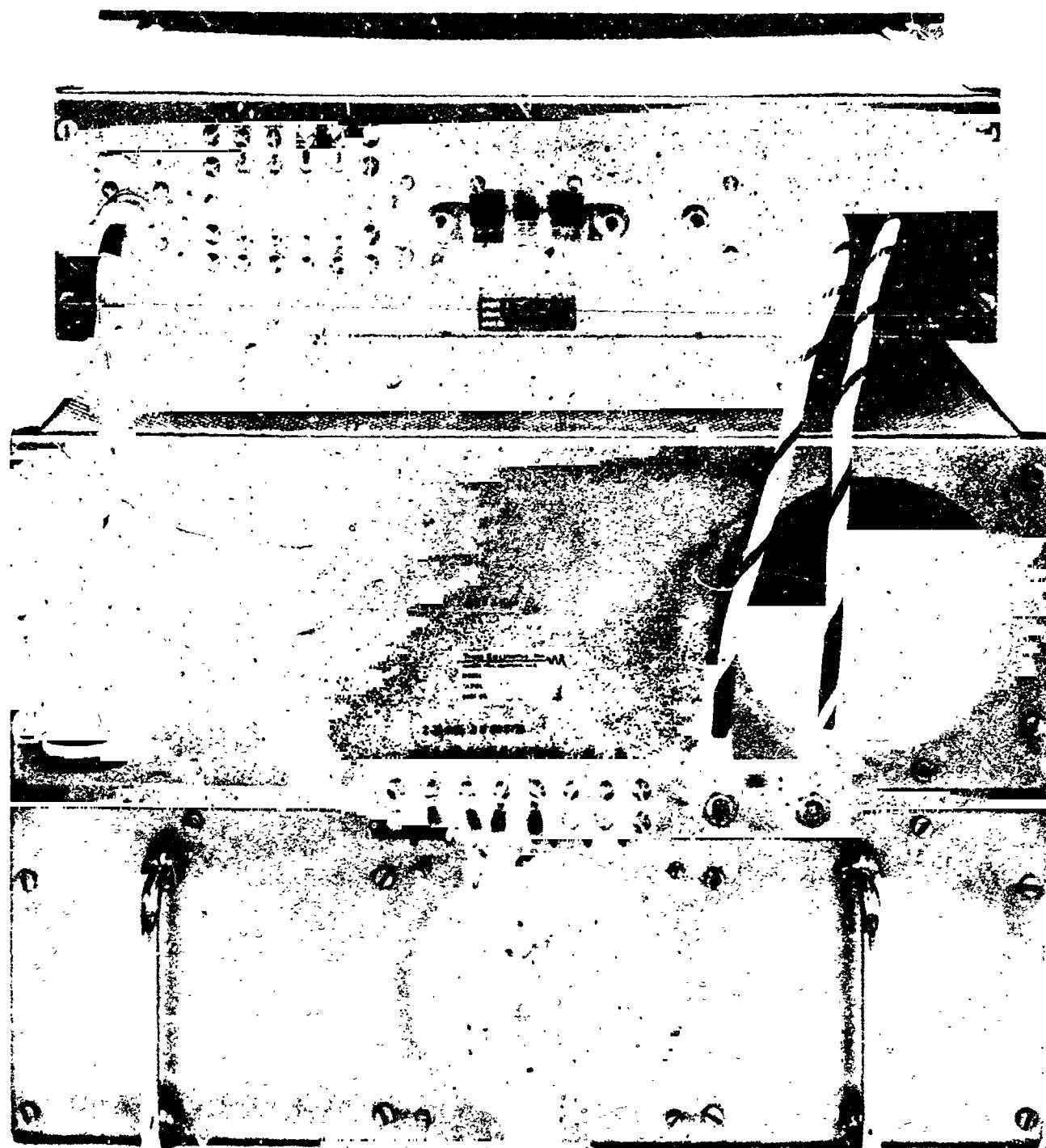
FRONT/RS VIEW, POWER SUPPLY,  
NORTRONICS EARTH-MOON SIMULATOR  
(PHOTO 190750)

FIGURE 6.8

N O R T R O N I C S



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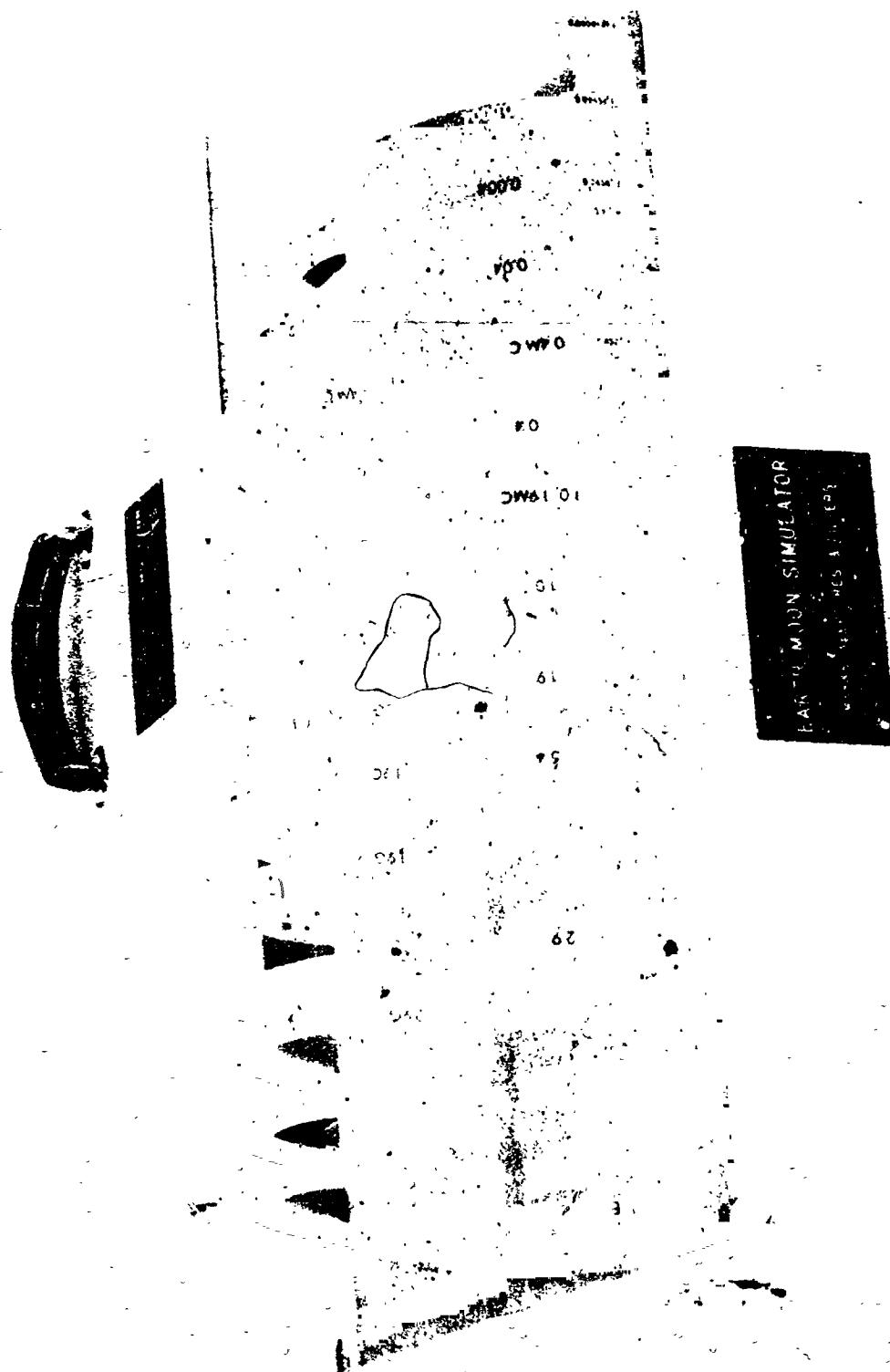
REAR VIEW, POWER SUPPLY,  
NORTRONICS EARTH-MOON SIMULATOR  
(PHOTO 190751)

FIGURE 6.9

N O R T R O N I C S



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MASK, APERTURE, AND FILTER CASE,  
NORTRONICS EARTH-MOON SIMULATOR  
(PHOTO 190749)

FIGURE 6.10